ARVE Technical Report #2

A spline fit to atmospheric CO_2 records from Antarctic ice cores and measured concentrations for the last 25,000 years

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1. Introduction

After several decades of collecting data on past atmospheric compositions from Antarctic firn, ice cores and direct measurements, there now exists an ample collection of atmospheric CO_2 records that cover the late Glacial and Holocene (roughly the past 25 ka) (Table 1). Each of these records covers a distinct segment of time, as well as each having a different level of resolution and uncertainty, relating to the precision of the measurement technique and/or variation between replicate samples. For earth system modeling, it desirable to have a continuous, annually-resolved record of atmospheric CO_2 concentrations that covers the last 25 ka. Given the large amount of data available, I wanted to find a way to combine these records, taking uncertainty into account, and create a "best fit" scenario. In this technical report, I describe the methods and results of a spline fit to a collection of CO_2 records, inversely weighted by uncertainty so that points with lower uncertainly carry more weight in the spline fit. The annually resolved dataset resulting from the spline fit was originally developed for input into a DGVM, but it could also be used for a wide variety of applications studying Earth's history.

2. Methods

All CO_2 records were arranged onto a time scale of years before present (BP 1950) and concatenated into a single 3-column file as years BP, atmospheric CO_2 concentration (ppm), and 1/uncertainty (weight). For most records, the uncertainty varied from point to point (e.g., Monnin et al. (2001)), while for some records there was a constant uncertainty around each point (e.g., all points from the Etheridge (1996) dataset have an uncertainty of 1.2). By taking the inverse of the standard deviation as a weight, the larger the uncertainty of a point, the lesser amount of weight it has for the spline fit.

This concatenated data was then used as input into R (R Core Development Team, 2009), where years BP and CO_2 concentration were assigned as x and y variables, respectively, and 1/standard deviation was the weight of each data point. Next, the smooth spline function in R was used to fit a spline to the data, taking the weight into account and producing an annual sequence of CO_2 concentrations from 25,000 years BP to present day (2010).

3. Results

The resulting spline fit is shown overlaying the original CO_2 data in Figure 1.

Our results show only small fluctuations above and below 190 ppm of atmospheric CO_2 from 25 ka BP until 17.5 ka BP, at which point CO_2 concentrations start to increase steadily at ~20 ppm ka^{-1}. Data points in this area (from 25 ka BP to ~18 ka BP) are fairly scattered and the spline is most closely fit to the EPICA Dome C data (Monnin et al., 2001; Schwander et al., 2001), which has the lowest uncertainty of the data in this region of the plot. Conversely, the Byrd dataset (Neftel et al., 1988, Staffelbach et al., 1991), having the highest error, carries the least amount of weight in region of the spline fit.

Between 14 ka and 13 ka BP, a pause and even a slight decrease in CO_2 concentration from 240 ppm to 237 ppm can be observed. By 13.5 ka BP CO_2 concentrations were increasing steadily again until 12 ka BP, where atmospheric CO_2 reaches a local maximum of ~265 ppm. From this point CO_2 concentrations start to decrease to roughly 260 ppm by 8 ka BP, where another reversal occurred and for the next 6000 years CO_2 concentrations were increasing (overall rise ~ 20 ppm). Subsequently, from 1500 years BP until just prior to industrialization (ca. AD 1850) small oscillations in the CO_2 concentrations (hovering around 280 ppm) occurred in the CO_2 spline fit. Post-industrialization, ~100 years BP (AD 1850), the rise in CO_2 in the atmosphere appears nearly vertical as the atmospheric CO_2 concentration explodes with the combustion of fossil fuels, reaching a level of 386 ppm by year 2009.

4. Conclusions

Here I describe a method for performing a weighted spline fit to atmospheric CO_2 records. By taking uncertainty into account, the spline is adjusted to fit more closely to points with higher confidence. The annual data produced by the spline fit should provide the best estimates of atmospheric concentrations over the last 25,000 years.

5. References

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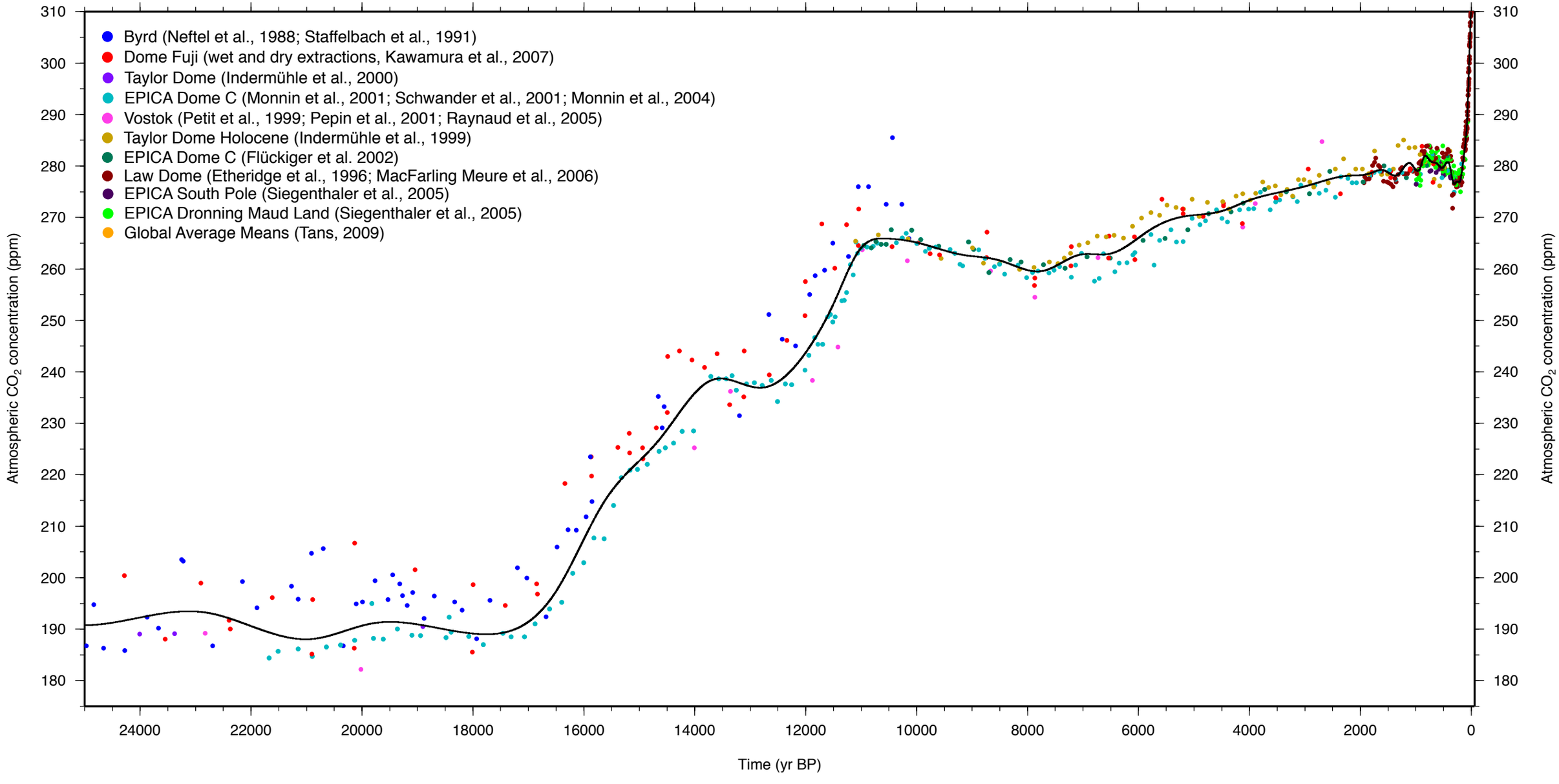
6. Table and Figure Captions

Table 1. The collection of atmospheric CO_2 records used in this study for generating a spline fit for the last 25 ka.

Figure 1. An agglomeration of the atmospheric CO_2 records used in this technical report from the last 25,000 years (colored circles) and resulting spline fit to this data (black line).

Site	Latitude	Longitude	Time span	URL	Original reference(s)
Byrd station	80.02° S	110.52° W	46.256 ka BP - 10.14 ka BP	ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/byrd/byrd-co2-2008.txt	Neftel et al., 1988; Staffelbach et al., 1991
Dome Fuji, dry extraction	77.32° S	39.7° E	263.62 ka BP - 688 years BP	ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/domefuji/df-co2-dry-260ka-2007.txt	Kawamura et al., 2007
Dome Fuji, wet extraction	77.32° S	39.7° E	337.57 ka BP - 695 years BP	ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/domefuji/df-co2-wet-340ka-2007.txt	Kawamura et al., 2003; Kawamura et al., 2007
Taylor Dome	77.8° S	158.7° E	62.067 ka BP - 20.145 ka BP	ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/taylor/taylor_co2-glacial.txt	Indermühle et al., 1999
Taylor Dome Holocene	77.8° S	158.7° E	11.1 ka BP - 390 years BP	ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/taylor/taylor_co2-holocene.txt	Indermühle et al., 2000
EPICA South Pole	90.0° S	--	993 years BP - 212 years BP	ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/maud/edml-co2-2005.txt	Siegenthaler et al., 2005
EPICA Dome C (Flückiger)	75.1° S	123.4° E	10.952 ka BP - 435 years BP	ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica_domec/dc_co2_hol_fl02.txt	Flückiger et al., 2002
EPICA Dome C (Monnin)	75.1° S	123.4° E	21.676 ka BP 9.067 ka BP	ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica_domec/domec_co2.txt	Monnin et al., 2004; Monnin et al., 2001; Schwander et al., 2001
EPICA Dronning Maud Land	75.0° S	0.07° E	AD 956 - AD 1888	ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/maud/edml-co2-2005.txt	Siegenthaler et al., 2005
Vostok station	78.47° S	106.8° E	44 ka BP - 2.3 ka BP	ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/vostok/co2nat.txt	Petit et al., 1999; Pepin et al., 2001; Raynaud et al., 2005
Law Dome	66.73° S	112.83° E	944 years BP - AD 1992	ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/law/law_co2.txt	MacFarling Meure et al., 2006; Etheridge et al., 1996; Trudinger et al., 2002
NOAA GMD sampling network global mean	--	--	AD 1980 - AD 2009	ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_mm_gl.txt	Tans, 2009


Byrd (Neftel et al., 1988; Staffelbach et al., 1991)
Dome Fuji (wet and dry extractions, Kawamura et al., 2007)
Taylor Dome (Indermühle et al., 2000)
EPICA Dome C (Monnin et al., 2001; Schwander et al., 2001; Monnin et al., 2004)
Vostok (Petit et al., 1999; Pepin et al., 2001; Raynaud et al., 2005)
Taylor Dome Holocene (Indermühle et al., 1999)
EPICA Dome C (Flückiger et al. 2002)
Law Dome (Etheridge et al., 1996; MacFarling Meure et al., 2006)
EPICA South Pole (Siegenthaler et al., 2005)
EPICA Dronning Maud Land (Siegenthaler et al., 2005)
Global Average Means (Tans, 2009)
Atmospheric CO_2 concentration (ppm)
Time (yr BP)
310
300
290
280
270
260
250
240
230
220
210
200
190
180
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0